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Status of Sorbent Injection Mercury Control Technology

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Introduction

This document presents a summary of the status and readiness of mercury control technology for the coal-fired boiler industry. The comments represent the perspective of individuals who have been involved in the air pollution control industry for the past 25 years. Much of this time has been spent conducting cutting-edge research and development and implementing new technology into this industry.

In must be noted that these comments reflect the bias of a company, ADA-ES, that plans to be a market leader in the $2-5 billion per year mercury control business that would develop as a result of pending EPA regulations. This is a tremendous business opportunity for ADA-ES and therefore we silently support government regulations that would establish a need for our technical expertise and commercial offerings.

However, we know that if technology implementation does not progress in a timely, logical, stepwise fashion, the results can be devastating to all those involved including pollution control vendors, power company users, and electricity consumers. In this document we will site several examples documenting the experiences of the industry with new technology for control of particulate matter and NO_x. In all of these cases, unexpected problems were encountered as the technology was scaled up and applied to different plants. These problems led to reduced reliability of the power plant as the plants were often forced to operate at reduced generating capacity and experienced frequent unplanned shutdowns for maintenance and repair of the new technology. During the early states of technology development, a significant variability in the operating costs is found. This is especially for retrofit technology applied to existing plants, where difference in available space and operating conditions leads to large variations in balance of plant impacts.

When technology is implemented on only a few early adopters, the problems are discovered and resolved with limited impact on the industry and consumer. However, if the technology is forced onto the industry too rapidly, then it's possible to jeopardize the reliability of large-scale generating capacity. Therefore, to minimize the potential detrimental impact of new pollution control technology on the capacity of electrical power suppliers, history has taught us that it would be foolish to bypass any of the following phases:

1. Laboratory testing: provides a cost effective means to determine general feasibility and test a variety of parameter.

2. Pilot-scale: test under actual flue gas conditions but at reduced scale.

3. Full-scale demonstration: scale up the size of the equipment and perform tests under optimum operating conditions to define capabilities and limits of the technology.

4. Full-scale demonstration at multiple sites: each new site represents new operating conditions and new challenges. Often a technology will work at one site and not at another. For example, test results from the 1999 ICR program showed that wet scrubbers could remove 98% of the mercury from one coal and only 5% of the mercury from another coal.

5. Long-term operation at several sites: Some problems don't show up until the first year or so of operation. An example presented below shows that the initial performance with hot-side ESPs was great and warranties were signed off only to find out the plant could not maintain full load after only 6 months.

6. Widespread Implementation: Problems will still be found at new sites, but most of the fatal flaws will have already been discovered and resolved.

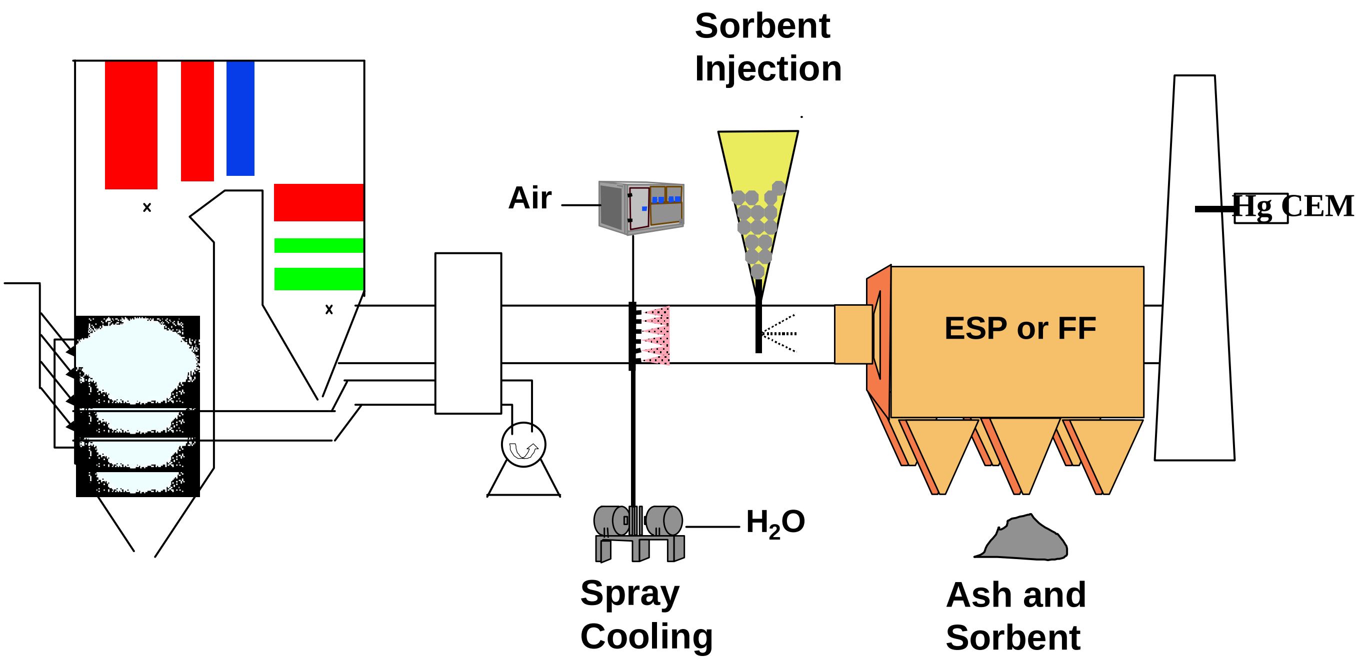
This paper describes the status of sorbent injection technology for mercury control. This is the most mature of all mercury control technologies as it has progressed to the early stages of the full-scale demonstration phase, with one on-site test completed earlier this year and the second currently underway. There are other technologies that will probably come along in the future including oxidation catalysts and barrier amalgamation devices. However, these are R&D concepts that are yet to reach the pilot-scale phase and are therefore three to five years behind the sorbent injection approach.

Background on Sorbent Injection

Sorbent injection technology involves the injection of a dry sorbent, such as activated carbon powder, into the flue gas duct somewhere between the air preheater and the ESP or FF, as shown in Figure 1. This is typically in the 250-350 degree F range. Vapor-phase mercury is adsorbed onto the activated carbon, which is then collected in the ESP or FF. The mercury-activated carbon interaction continues to occur in the ESP or FF. The technology can be used in conjunction with flue gas temperature control, usually accomplished through the injection of water (spay cooling) droplets into the flue gas. Pilot studies have shown in some cases lower temperatures can enhance the process.

A variation of the configuration shown in Figure 1 using a high air-to-cloth Pulse-Jet Baghouse installed downstream of the existing ESP was developed and patented by EPRI. This configuration, without carbon injection, is called COHPAC. When a sorbent is injected into the baghouse for pollutant control, the process is called TOXECON. This approach focuses on improving the efficiency of sorbent injection by providing high efficiency particulate collection as well as a good "contact" scheme for the sorbent and mercury (e.g. the FF). This technology also minimizes the amount of the flyash that can be contaminated by the mercury sorbent.

The most commonly studied sorbent for mercury control has been activated carbon. This material has been successfully used as a sorbent in municipal and hazardous waste combustors. Activated carbon is carbon that has been "treated" to reflect certain properties such as surface area, pore volume, pore size. Activated carbon can be manufactured from a variety of sources, (e.g. lignite, peat, coal, wood, etc.). More commonly, steam is used for activation, which requires carbonization at high temperatures in an oxygen-lean environment. As some carbon atoms are vaporized, the desired highly porous activated carbon is produced. Commercially, activated carbons are available in a range of particle sizes, as well as other performance characteristics.



Laboratory, pilot scale and modeling programs have indicated that the following parameters can affect the ultimate performance of the technology (Brown et al., 1999; Haythornthwaite et al., 1997; Meserole et al., 1999; Sjostrom et al., 1997):

- Particulate control device: ESP vs. fabric filter
- sorbent type and properties,
- gas-phase mercury species (Hg^0 or $HgCl_2$),
- temperature,
- concentration of acid gases (HCl, SO_2, NO, NO_2) in the flue gas,
- residence time

The type of particulate control equipment is a key parameter defining both the amount of sorbent that is required and provides the ultimate limitation of the amount of mercury that can be removed. When the sorbent is injected into the flue gas it mixes with the gas and flows downstream. This provides an opportunity for the mercury in the gas to contact the sorbent where it is removed. This is call "in flight" capture. The sorbent is then collected in the particulate control device where there is a second opportunity for sorbent to contact the mercury in the gas.

In an ESP, the carbon is collected on plates that are spaced parallel to the gas flow. Although the residence time in the ESP can be several seconds long, there is a limited amount of contact between the gas and the collected particles because the gas can be as far as four inches from the plates. On the other hand, the fabric filter provides the ideal opportunity for good interaction between the gas and the sorbent as the gas makes intimate contact with the sorbent collected on the filter. Therefore, sites with fabric filters will achieve higher levels of mercury removal and lower levels of sorbent utilization. This was confirmed at the first ADA-ES full-scale demonstration at the Alabama Power Gaston Station burning a low-sulfur bituminous coal (Bustard et al., 2001a). By injecting upstream of a COHPAC fabric filter it was possible to obtain 90% mercury removal over short periods of time and 80-85% removal during a 10 day continuous run. Unfortunately, only 10% of the coal-fired power plants in the US have fabric filters. In addition, tests need to be conducted to determine if similar results can be achieved on units with baghouses that burn PRB coal

Status of Sorbent Injection Technology

ADA-ES is performing the first full-scale demonstrations of this technology at four different power plants (Durham et al., 2001a). The first program was completed in the spring of 2001 at Alabama Power Gaston. The second program is ongoing at the Wisconsin Electric Pleasant Prairie Power Plant and will be completed before the end of the year, with publicly available results in early 2002. The Wisconsin Electric test program is very important because the plant burns a Powder River Basin (PRB) coal and has an ESP. This is a configuration that is representative of a large number of power plants in the US.

During these demonstrations, we have demonstrated that it is possible to design, build, and operate equipment at a scale capable of treating power plant flue gas. To date, the injection equipment has operated successfully at both sites. However, it must be noted that these tests only run for very short periods of time with the longest continuous runs being several days. In addition, the government-supported programs allow the luxury of operating the equipment using a large, expert staff of highly trained field engineers and specialists with many years of experience. This is typical of early stages of development and demonstration of technology. There is a significant amount of work that must be done before equipment will be ready to be turned over to plant personnel for continuous reliable operation.

In addition, there are a number of key issues that must be addressed over the next several years before this technology can be viable for a large number of plants. These issues include:

- Are there unexpected interactions between the injected sorbents and flue gas constituents?

- What is the long-term impact of the injected sorbent on the operation and performance of the particulate control device?

- What is the impact of the sale and reuse of the flyash after it is contaminated with the carbon?

- What is a reasonable range of cost estimates for technology application across various configurations of particulate control devices, and what is the shape of the cost curve for various mercury reduction levels?

Lessons Learned from Past Experience Implementing New Air Pollution Control Technology into the Coal-Fired Boiler Industry

Since the first Clean Air of 1970, the power industry has gone through several rounds of implementing air pollution control technology for particulates, sulfur dioxide, and nitrogen dioxides. In each case, there were very similar experiences as the new technology was applied to this difficult industry including:

- Unexpected reactions between chemical reagents added to control the pollutants and flue gas constituents;

- Changes in coal characteristics and plant operating conditions causing wide variation in performance; and

- Significant O&M problems that did not show up until after long-term operation.

- Secondary effects on other components of the power plants are discovered; examples include higher carbon in the ash from low-NOx burners, ammonia in the ash SNCR and SCR, and changes in concrete characteristics when new chemicals are added to the flyash.

In all of these cases the problems that resulted from the new technology had a significant impact on the reliability of power generation. The plants were forced to operate at reduced loads and suffered many unplanned shutdowns for maintenance and repair. Over time solutions to these operating problems were developed and the technologies now operate more reliably and successfully. The severity of the impact of the initial problems, both in cost to the power consumer and in the reduction of available capacity, depended upon how widespread the technology was applied during the early adopter phase. For example, the case history of hot-side ESPs presented at the end of this document has cost the industry over a billion dollars because after early success, the technology was quickly applied to 150 power plants. Several other case histories are presented which show that when the first wave of implementation in limited to only a few plants, the early design and operating problems can be resolved without widespread impact on the industry.

Possible Limiting Constraints to the Technology

Figure 1 shows that the final part of the sorbent injection system is a continuous emission monitor (CEM) on the stack to monitor mercury emissions. During the first test program, it became obvious that sorbent injection technology needs a CEM as a process control device. Many plants burn coals from different mines, which can create variations in the amount of mercury that must be collected. It is necessary to measure the concentration of mercury in real time in order to adjust the feed rate of the sorbent. This will provide a means to assure continuous performance of the mercury removal technology.

However, the difficulty of accurately measuring mercury in flue gas at very low concentrations (1 part per billion) makes this a very challenging task. The data being collected for the ADA-ES program is obtained by team member Apogee Scientific. This group has been working on this technology for over ten years and has advanced the measurement equipment to a state where reliable data can be produced. However, to make the system work, it is necessary to have the inventor of the instrument on site to operate one instrument while a field specialist with 20 years of field testing experience operates a second instrument. At the current rate of advancement in this technology, it is unknown whether reliable CEMs will be available able to meet a 2007 EPA implementation schedule.

Another significant barrier will be the cost of building new kilns and furnaces that will be necessary to increase the production of activated carbon to meet the potential market for coal-fired boilers. The current market for activated carbon in the US is 250,000 tons/yr. Once mercury regulations are fully implemented, this could increase the demand to 2-3 million tons/yr. In addition, the activated carbon suppliers will be very hesitant to invest capital resources to increase capacity based on the promise of a new regulation, especially by an individual state. Ten years ago, the carbon industry increased capacity when EPA announced that they were going to tighten up drinking water standards. After the new capacity was added, EPA did not follow up with new regulations thus producing a glut of activated carbon. Some companies went out of business because of this, and the industry as a whole is just now recovering.

In addition to being unwilling to build new capacity for future regulations, the EPA permitting process may additionally slow down the process. The production of activated carbon requires the construction of new major sources processing lignite and other carbon-bearing fuels. Obtaining permits for these new facilities may add years to the timeline to increased capacity.

Conclusions

As with all other air pollution control technology, sorbent-based mercury control is a developing technology that needs to go through a phased approach as it matures to become accepted as commercially viable. This approach to implementation of new technology has evolved from thirty years of lessons learned by the power industry from applying new technology. If an attempt is made to accelerate technology development by skipping these steps, there will be significant danger that operating problems could arise that will lead to untimely shut downs of the plants using the technology.

The schedule announced by EPA to require widespread implementation of mercury control for the coal-fired boiler industry by 2007 represents an extremely challenging schedule. To advance the sorbent injection technology to meet this tight timeframe, we propose the following schedule to allow us accomplish this in a controlled manner that doesn't put generation capacity at risk:

- Short-term full-scale evaluations (2000-2003)
    - Parametric evaluations
    - Multiple sites to evaluate different configurations and fuels

- Long-term full-scale demonstrations (2003-2005)
- First commercial installations at a few early adopters (2005-2007)
- Resolve issues on ash disposal (2001-2005)
- Increase production of activated carbon by factor of ten (2005-2007)

As far as the issue of what levels of mercury control will be achievable in the next ten years, it will depend primarily upon the type of existing particulate control equipment. Based upon the results at Alabama Power's Gaston Station, we believe that 90% could be achievable at power plants burning bituminous coal with fabric filters (baghouses). Additional tests are required to document mercury removal at sites burning PRB coals. To operate continuously at these conditions, the baghouse will have to be designed ahead of time to handle the additional loading due to the activated carbon. It was discovered at Gaston, that the current COHPAC baghouse design does not have the additional capacity to collect the sorbent without operating at higher pressure drops and/or increased cleaning frequency. This could potentially impact generation to maintain pressure drop limitations and will have a severe impact on bag life.

For the power plants with ESPs, which represent 90% of the US power plants, reaching a 90% level of mercury removal is probably not achievable for the vast majority of these units without major investment in new capital equipment. The mercury removal for these units will be limited because of the poorer contact between the sorbent and the gas. For each unit, the ultimate mercury removal level that can be achieved will depend on the size of the ESP, the residence time in the ductwork, and characteristics of the coal. We estimate that most units will fall in a range of 30 to 70 percent mercury removal.

Case Histories

Case History: Hot-Side ESPs

The 1970 Clean Air Act required reduction in emissions of sulfur dioxide, SO_2, from coal-fired power plants. Many utilities opted to reduce SO_2 by burning coal with a low sulfur content. These fuels were available in large supplies located in the Western States. However, the lower sulfur in the coal resulted in problems with ESP due to high-resistivity flyash.

An attempt was made to avoid resistivity problems by installing the ESP on the "hot-side" or upstream side of the air preheater rather than on the "cold-side", downstream side, of the air preheater, which was the conventional design. This would increase the temperature of the flue gas from approximately 300 ^oF to 800 ^oF. The increase in operating temperature would result in a significant decrease in resistivity.

Following early short-term success, hot-side ESPs were rapidly accepted by the industry and were installed on about 150 boiler units to meet legislated emission standards. In 1975, hot-side ESP represented 70% of utility ESP sales. However, as these new ESP came on-line and began operating for an extended period of time, many of them began experiencing time-dependent deterioration of electrical operating conditions that resulted in poorer collection efficiency and increased emissions and opacity problems. After several years and many millions of dollars spent on R&D, the problem was diagnosed as sodium depletion for which there was no cure.

Utilities with hot-side ESP have been struggling with problems with these systems for over 25 years. Hot-side ESPs have cost the industry well over a billion dollars. Power plants were forced to either derate the unit or shut down to clean the ESP by washing or sandblasting the plates. However the ESPs begin to deteriorate after a month or so of operation and the cleaning cycle must be continuously repeated. On the average, these ESPs had to be cleaned every four months and the cleanings would require the plant to be off line for as much as a week at a time.

Other more costly remedies included conversion to a cold-side ESP or fabric filter. Converting a hot-side ESP to a cold-side unit involves extensive modification to the existing ductwork and moving the air preheater. Costs to accomplish these conversions have ranged from $20 to $50 million for each unit.

Case History: COHPAC

To meet more stringent emission regulations at Big Brown Station, TXU chose COHPAC (Compact Hybrid Particulate Collector) as a particulate control technology for both 575-MW units. COHPAC is a pulse-jet baghouse installed downstream of an existing electrostatic precipitator (ESP), a technology patented by EPRI (Bustard et al., 2001b).

After some initial laboratory testing, ADA-ES was hired by EPRI to operate a pilot-scale test program beginning in the Spring of 1990 to further refine the technology. The pilot scale tests identified a design flaw in the flow distribution that was resolved and tested further. Using data obtained from several years of successful operation of the pilot plant, a 150 MW unit was designed and installed. The 150 MW unit operated successfully for almost a year so the utility decided to implement the technology of two 600 MW plants. Unit 2 COHPAC began operation in November 1995 and Unit 1 COHPAC began operation in April 1996.

Based on results from a 150 MW demonstration baghouse in 1993 - 1994, achieving a two-year bag life was believed to be possible. A two-year bag life guarantee was also provided by the vendor. However, long-term operation of COHPAC revealed that bag life was less than the anticipated two-year minimum. It was found that bag fabric strength deteriorated rapidly and the bags developed holes and tears. Bags were failed after less than 12 months of operation.

In addition to bag breakage, another problem presented itself during early operation. Pressure drop (or drag) across the filter fabrics had become unacceptably high, requiring partial bypass of flue gas to keep baghouse pressure drop within the limits established by the vendor. This inability of COHPAC to filter full flue gas flow increased opacity and, under some conditions, forced Big Brown operators to reduce the output of the generators to maintain opacity below the 20% limit. It was apparent that even if bag breakage could be avoided for two years, it was quite likely that the bags would be unusable due to high pressure drop.

TXU and EPRI teamed on a program to identify the cause of the early bag failures and high pressure drop and find solutions to these problems. No additional derating of generation occurred after the first year of operation because of non-standard changes to the operating logic. After 6 years of operation, bag life is still less than 2 years on many of the bags. This program is still active today in an effort to develop novel fabric and bags that may provide pressure drop relief (Bustard et al., 2001).

Fortunately for Alabama Power, the limitations of the COHPAC design were identified before the final design of the COHPAC baghouses for Plant Gaston. These limitations were incorporated and the Gaston COHPAC unit operated successfully for 4 years on the same set of bags.

The first demonstration using activated carbon injection into a baghouse for mercury control was conducted on Gaston Unit 3 COHPAC in spring of 2001. Short-term tests showed 80 - 85% mercury removal (Bustard et al., 2001a). COHPAC is now not only a proven, cost effective option for improving particulate emissions; if mercury removal results can be confirmed during longer-term operation and at application at other sites, COHPAC will be a viable technology for mercury control. The lessons learned at Big Brown helped in the successful design of the Gaston baghouses.

Case History: SCR Commercialization in the US

- SCR technology was developed and pilot-tested in the United States in the 1970's. It was never used commercially due to high costs and availability of low-NO_x combustion alternatives.

- First commercial retrofit installations on coal occurred in Europe and Japan starting in 1986. By 1995, there were over 200 installations. About 120 of these were in Germany, and the majority of these were applied to low-sulfur high-ash brown coals (lignite).

- The European experience revealed problems with catalyst poisoning on some coals, but these were addressed with design improvements in the decade that units were installed. However, differences in coal composition, boiler design, balance-of-plant equipment design, and operating and maintenance practices made it difficult to apply the European experience to US boilers.

- In the US, DoE and EPRI funded several long-term pilot tests to address the differences between European and US coals. DoE ran a two-year Clean Coal project at Southern Company, Plant Crist. They operated nine SCR slipstream reactors in parallel (six 0.2-MW reactors and three 2.5-MW reactors), each with a different catalyst. Operating time varied from about 2000 to 6000 hours. EPRI built and operated several 1-MW reactors at several plants. Results were encouraging enough that a few power companies placed contracts for SCR reactors in the 1990's.

- Six coal-fired SCR installations were up and running in the US by 1996. Out of these, five were built on new boilers and one was retrofitted to an existing boiler. The target NO_x reductions ranged from 50-70%, though it was found that higher NO_x reductions could be sustained.

- More SCR operating problems were encountered on these six installations. SO_3 formation increased and caused sulfate plume problems, in spite of catalyst formulation changes designed to minimize SO_2 conversion to SO_3. Ammonia slip and resulting air preheater pluggage occurred on each installation. Fluctuations in reactor inlet temperature and inlet NO_x concentrations were responsible for many of these ammonia slip problems. Adding more catalyst was another (costly) way to avoid ammonia slip.

- Currently, there are over 40 retrofit SCR reactors being constructed to meet Title I SIP-call requirements. These new units, including the SCR being installed at the Wisconsin Electric Pleasant Power Plant, all incorporate design modifications developed from lessons learned from several years' operation at the first 6 sites. The new SCR designs have included air preheater rebuilds to reduce the impact of ammonium sulfate pluggage. The industry has moved from ammonia injection grids to static mixers upstream of the SCR reactor in order to improve NH_3/NO_x ratio going into the reactor so that higher NO_x reductions can be maintained without ammonia slip. Reactors are also equipped with better temperature control to minimize SO_3 formation.

- Recent SCR installations at New Madrid, Somerset, Gavin, et al show that the sulfate plume problem is not yet solved. Also, catalyst poisoning by calcium sulfate when burning PRB coal is still being evaluated, though initial data from New Madrid looks promising.

In conclusion, the US Power Generation Industry has benefited from careful, step-wise introduction of SCR technology for NO_x control. Designs have been conservative, and reactor problems (though costly) have not adversely impacted boiler capacity or availability.

Case History: ADA-ES Flue Gas Conditioning

ADA-ES has commercialized a family of patented and proprietary, flue gas conditioning additives to provide utilities and industries with a cost-effective means of complying with environmental regulations on particulate emissions and opacity. The flue gas conditioning additives decrease particle resistivity and improve the performance of ESPs with resistivity related performance problems. Based upon the success of this technology, the Air and Waste Management Association selected ADA-ES the 2001 Sensenbaugh Award for outstanding contribution in air pollution control (Durham, 2001).

The commercialization of this technology followed the path of all other air pollution technology in which new problems were discovered at each phase of the development and implementation. The technology was conceived in 1990 when The Department of Energy (DOE) funded ADA-ES to identify, evaluate, and develop cost-effective ESP conditioning agents to improve removal of fine particle air toxics from coal-fired combustion flue gas streams. The research program, which is described in detail in Durham et al., (1995, 1996), encompassed an extensive laboratory screening, followed by bench-scale and pilot-scale tests. Discovery of a promising resistivity modifier in August 1994 led to a further round of laboratory and pilot-scale field testing in late 1994.

The Electric Power Research Institute and Central & SouthWest Services funded the first full-scale demonstration of the technology (Dharmarajan et al. 1996). Following this successful first demonstration, ADA-ES continued the short-term demonstration at several different plants, demonstrating it at a variety of utilities with both hot-side and cold-side ESPs. Results from these programs are described in several papers (Baldrey et al., 1997; Durham, et al. 1997a,b; Martin et al., 1997).

Based on the success of the short-term, full-scale demonstrations, the first commercial system was installed at the Alliant Columbia station in Portage, Wisconsin. During the first month of operation, it was discovered that the ADA-ES reagent was reacting with another chemical being used by the plant. The reaction led to severe fouling of the unit requiring the plant to shut down this 550 MW plant for a week to clean the unit.

After three months of operation at the second and third commercial site, pressure drop buildup across the air preheater increased to a point that load could not be maintained. This pluggage required the plant to shut down these two 500 MW plants for over a week. This pluggage was directly attributed to the use of the ADA-ES chemical. This site was using a cruder grade of the active chemical. It has been concluded that impurities found in this chemical evaporate at hot-side temperatures and then condense onto the cooler air preheater zones leading to buildups.

Both of these problems have been resolved through development of a 2nd and 3rd generation chemical. With the improved chemicals, the technology has now been operating continuously and successfully for over three years at the Columbia station. Having resolved these problems on the first few installation, we are now implementing the technology at multiple sites (Durham, et al., 2001b).

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